

1 **SELECTING A TRACK DENSITY FOR EACH DISK SURFACE OF A**
2 **DISK DRIVE BASED ON HEAD CHARACTERISTIC**

3
4 **BACKGROUND OF THE INVENTION**

5 **Field of the Invention**

6 The present invention relates to disk drives for computer systems. More particularly, the
7 present invention relates to selecting a track density for each disk surface of a disk drive based on
8 a head characteristic.

9 **Description of the Prior Art**

10 FIG. 1A and 1B show a prior art head disk assembly (HDA) comprising a disk 2 having a
11 top surface 4A and a bottom surface 4B. The disk 2 is rotated about a center axis while
12 respective top and bottom heads 6A and 6B write and read data to/from the respective disk
13 surfaces 4A and 4B. The heads 6A and 6B are attached to the distal end of respective actuator
14 arms 8A and 8B which are rotated about a pivot by a voice coil motor (VCM) 10 in order to
15 actuate the heads 6A and 6B radially over the disk surfaces 4A and 4B. Each disk surface 4A
16 and 4B comprises a number of radially spaced, concentric tracks (e.g., tracks 12A on disk surface
17 4A) as defined by a number of embedded servo sectors (e.g., servo sectors 14A on disk surface
18 4A). The embedded servo sectors 14A are read by head 6A and processed by a servo control
19 system in order to maintain the head 6A over a center of a target track while writing or reading
20 data. The embedded servo sectors 14A may be written to the disk surface 4A using an external
21 servo writer or using internal circuitry during a self-servo writing process.

22 The overall recording density of each disk surface is determined in part by the track
23 density or radial tracks per inch (TPI). Since the embedded servo sectors define the tracks, the
24 track density is established when the embedded servo sectors are written to the disk during the
25 servo writing process. The track density and therefore the recording density of the disk drive is
26 limited by the characteristics of the head such as the width of the head. In the past, a nominal
27 track density has been selected to servo write all of the disk surfaces corresponding to the

1 average characteristics for the type of head used to manufacture a family of disk drives. If during
2 a "burn-in" process of each disk drive the track density is found to be too high for any one of the
3 heads, the entire disk drive may be discarded as defective, the head/disk replaced, or the
4 respective disk surface marked as unusable.

5 U.S. Patent No. 6,091,559 discloses a method for optimizing the track density for each
6 disk surface by measuring a track width written by each head. The track width is measured by
7 writing a first pattern to the disk, and then reading the first pattern to generate a first read signal
8 amplitude measurement A0. A second pattern is then written on both sides of the first pattern at
9 a predetermined radial offset, and the first pattern is read again to generate a second read signal
10 amplitude measurement A1. A track density is selected for the disk surface in response to a ratio
11 between the first and second read signal amplitude measurements A0 and A1. A problem with
12 this technique is that the first pattern is read over two revolutions of the disk: once before the
13 second pattern is written and again after the second pattern is written.

14 There is, therefore, a need for an improved technique for estimating the optimal track
15 density of each disk surface in a disk drive.

16 SUMMARY OF THE INVENTION

17 The present invention may be regarded as a method for selecting a track density for a disk
18 surface of a disk drive. The disk drive comprises a disk including the disk surface and a head
19 actuated over the disk surface. A first pattern is written along a first circumferential path of the
20 disk surface, wherein the first circumferential path comprises a first set of arcuate sections
21 interleaved with a second set of arcuate sections. A second pattern is written along a second
22 circumferential path during time intervals corresponding to the first set of arcuate sections,
23 wherein the second circumferential path is radially offset from the first circumferential path. The
24 head is positioned substantially over the center of the first circumferential path and during time
25 intervals corresponding to the second set of arcuate sections, the first pattern is read to generate a
26 first read signal amplitude measurement A0, and during time intervals corresponding to the first
27 set of arcuate sections, the first pattern is read to generate a second read signal amplitude

1 measurement A1. A track density is selected in response to A0 and A1, wherein the track density
2 is for use in writing embedded servo sectors to the disk surface.

3 In one embodiment, the center of the first circumferential path is located prior to the steps
4 of reading the first pattern to generate the first and second read signal amplitude measurements
5 A0 and A1. The head is positioned at different locations with respect to the first circumferential
6 path to read the first pattern, wherein the center of the first circumferential path is selected as the
7 head position that maximizes the read signal amplitude.

8 In another embodiment, the track density is selected in response to a ratio of A1 to A0.

9 In yet another embodiment, the first pattern comprises a first fundamental frequency and
10 the second pattern comprises a second fundamental frequency substantially different than the first
11 fundamental frequency. In one embodiment, the first pattern writes a predetermined pattern of
12 magnetic transitions on the disk surface and the second pattern writes a DC erase signal to the
13 disk surface.

14 In one embodiment, prior to the step of positioning the head substantially over the center
15 of the first circumferential path and reading the first pattern to generate the first and second read
16 signal amplitude measurement A0 and A1, the head is positioned substantially over a center of a
17 third circumferential path and the second pattern is written along the third circumferential path.
18 The second circumferential path is radially offset in a first direction from the first circumferential
19 path, the third circumferential path is radially offset in a second direction from the first
20 circumferential path, and the first direction is substantially opposite the second direction.

21 BRIEF DESCRIPTION OF THE DRAWINGS

22 FIGs. 1A and 1B show a prior art head disk assembly (HDA) comprising a disk having a
23 top surface and a bottom surface.

24 FIG. 2 is a flow diagram according to an embodiment of the present invention for
25 selecting a track density of each disk surface by writing a primary pattern in first and second
26 sections, writing an interference pattern radially offset from the primary pattern in the second

1 sections, and reading the primary pattern during the first and second sections to generate a first
2 and second read signal amplitude measurements A0 and A1.

3 FIG. 3 is a more detailed flow diagram according to an embodiment of the present
4 invention wherein the first sections comprise even intervals and the second sections comprise
5 odd intervals.

6 FIG. 4 is a flow diagram according to an embodiment of the present invention for locating
7 a center of the primary pattern before reading the primary pattern.

8 FIG. 5 is a flow diagram according to an embodiment of the present invention wherein
9 the interference pattern is written on both sides of the primary pattern during the odd intervals.

10 **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

11 FIG. 2 shows a method for selecting a track density for a disk surface of a disk drive
12 according to an embodiment of the present invention, wherein the disk drive comprises a disk
13 including the disk surface and a head actuated over the disk surface. At step 16 a first pattern is
14 written along a first circumferential path of the disk surface, wherein the first circumferential
15 path comprises a first set of arcuate sections interleaved with a second set of arcuate sections. At
16 step 18 a second pattern is written along a second circumferential path during time intervals
17 corresponding to the first set of arcuate sections, wherein the second circumferential path is
18 radially offset from the first circumferential path. At step 20 the head is positioned substantially
19 over the center of the first circumferential path and during time intervals corresponding to the
20 second set of arcuate sections, the first pattern is read to generate a first read signal amplitude
21 measurement A0, and during time intervals corresponding to the first set of arcuate sections, the
22 first pattern is read to generate a second read signal amplitude measurement A1. At step 22 a
23 track density is selected in response to A0 and A1, wherein at step 24 the track density is for use
24 in writing embedded servo sectors to the disk surface.

25 The method of writing a primary pattern and an interference pattern radially offset from
26 the primary pattern provides an accurate measurement of the track pitch capability of the
27 combined width of the read and write elements. Further, by writing the interference pattern in

1 sections, the first and second read signal amplitude measurements A0 and A1 can be generated
2 by reading the first circumferential path over one revolution of the disk.

3 The read signal amplitude measurements A0 and A1 may be generated using any suitable
4 technique, such as sampling the read signal at a predetermined time interval and summing the
5 sample values. Further, any suitable mathematical relationship may be employed to generate a
6 track pitch value (TPV) for selecting an appropriate track density. For example, in one
7 embodiment a TPV is generated using the mathematical relationship $A1/A0$, and in an alternative
8 embodiment generated using the mathematical relationship $(A0-A1)/A0$. In addition, the second
9 pattern may be written at any suitable radial offset from the center of the first circumferential
10 path. For example, the second pattern may be written at a radial offset equal to 70% of the width
11 of a data track at a predetermined track density. Still further, the process may be executed by an
12 external servo writer or using the internal circuitry of the disk drive during a self-servo writing
13 operation.

14 The first and second patterns may comprise any suitable frequency components. In one
15 embodiment, the first pattern comprises a first fundamental frequency and the second pattern
16 comprises a second fundamental frequency substantially different than the first fundamental
17 frequency. For example, in one embodiment, the first pattern writes a predetermined pattern of
18 magnetic transitions on the disk surface and the second pattern writes a DC erase signal on the
19 disk surface. If the second pattern writes a number of magnetic transitions on the disk surface
20 (i.e., comprises a non-DC fundamental frequency), a band-pass filter may be employed to read
21 the first pattern wherein the band-pass filter passes the fundamental frequency of the first pattern.

22 FIG. 3 shows a more detailed flow diagram according to an embodiment of the present
23 invention wherein at step 26 the center of the first circumferential path is located before reading
24 the first pattern. This step is necessary in disk drives employing a head comprising a read
25 element offset from the write element, such as with a magnetoresistive head. Since the offset is
26 unknown, the center of the first circumferential path with respect to the read element is
27 determined before reading the first pattern. In one embodiment, the step of locating the center of

1 the first circumferential path comprises the steps of positioning the head at different locations
2 with respect to the first circumferential path to read the first pattern, wherein the center of the
3 first circumferential path is selected as the head position that maximizes the read signal
4 amplitude. This is illustrated by the flow diagram of FIG. 4 wherein at step 30 an OFFSET value
5 is initialized to a maximum negative value. At step 32 the head is positioned at approximately
6 the center of the first circumferential path plus the OFFSET. At step 34 the first pattern is read
7 from the first circumferential path and a read signal amplitude measured. If at step 36 the read
8 signal amplitude is the maximum, then at step 38 the head position is saved and used as the
9 center of the first circumferential path. If at step 40 there are more deltas to consider, then at step
10 42 a delta is added to the OFFSET and the process repeated starting at step 32.

11 Referring again to the flow diagram of FIG. 3, having located the center of the first
12 circumferential path, at step 20 the first pattern is read from the center of the first circumferential
13 path during the respective time intervals to generate the first and second read signal amplitude
14 measurements A0 and A1. At step 44 a TPV is calculated as the ratio $A1/A0$, and at step 46 the
15 TPV is compared to thresholds to select the appropriate track density to servo write the disk
16 surface. In the embodiment illustrated in step 46 of FIG. 3, the disk surface may be written with
17 one of three track density values as selected by comparing the TPV to two thresholds TH1 and
18 TH2. However, any suitable resolution may be employed for the track density values, and any
19 suitable technique employed for mapping the TPV into the appropriate track density (e.g.,
20 converting the TPV into an index for indexing a table or an array).

21 FIG. 5 is a flow diagram which augments the flow diagram of FIG. 3 by writing the
22 second pattern on both sides of the first circumferential path. That is, at step 48 the second
23 pattern is written on the opposite side of the circumferential path during time intervals
24 corresponding to the first set of arcuate sections (the odd sections) similar to step 18. Writing the
25 second pattern on both sides of the first circumferential path may provide a more accurate
26 measurement of the track pitch capability of the combined width of the read and write elements.